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Exploring the Learning Outcomes with Various Technologies - Proposing Design Principles for Virtual Reality Learning Environments

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Abstract

The study compares three virtual learning environments: VR, 3D videos and 2D videos. Following Bloom's taxonomy of learning outcomes, we measure remembering, understanding and ability to apply. We also apply the affordance theory framework to explain the differences between these virtual learning environments. Based on the results, we propose design principles for VR learning environments. The results suggest that VR has its advantages on the apply -level, or higher, as it outperforms the other two technologies at this level. In addition, several design principles are suggested, such as customized learning, challenging learning environments, multi-sensory effects, immersion, interactivity, 3D-dimensionality, engagement as well as motivation towards the content and technology. The results highlight the importance of choosing the right technology when designing virtual learning environments. This study demonstrates how virtual environment affordances and equivalent scales can be used in making those decisions.

1. Introduction

Various digital platforms used in entertainment and gaming have been found useful also in education. The fast development of these technologies has opened new previously unseen possibilities, which has led to the introduction of new teaching contents and methods [22]. For example, Massive Open Online Courses (MOOCs) and various mobile learning applications are widely used. However, many of the existing teaching methods, contents and evaluation schemes are not applicable as such when introducing new teaching technology, and completely new course designs are usually required [46].

Immersive Virtual Reality (VR) with user interfaces that utilize Head Mounted Displays (HMDs) has emerged as a new promising teaching and learning technology [7]. VR-based learning environments make it possible to visit places and do things that are not otherwise possible or are too expensive or dangerous [15]. In addition, VR allows the learner's cognition to shift from representational learning to conceptual learning [45]. This is increasingly important as students need to learn to analyze and manipulate information from multiple sources.

Existing research on VR-based teaching and learning suggests that the content of the application matters. For example, a VR environment that included modelled chemistry laboratory tools and methods produced equal learning results than a traditional, physical learning environment [40]. When this is the case, the only benefit of VR-based teaching relates to the economies of scale. However, in the case of complex and abstract contents and phenomena in the field of physics that are challenging to be presented with traditional learning tools and methods, VR has been found to help the students to concentrate [32]. Other research also suggests that VR suits particularly well to teaching complex and abstract things that cannot be easily visualized in real-world or by some other applications (e.g. [41,43]). In addition, VR can be used to provide immersive and emotional learning experiences, which students remember better and longer [14].

Design science research [34] as well as pedagogical literature studying learning environments in general have adopted the term "affordances" to describe the various features that learning

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environments afford the learner to do [44]. While there are plenty of studies showing various virtual learning environment affordances, there still seems to be a lack of understanding on how these affordances vary between different technologies as there are no explicit comparative studies. In addition, there is a lack of studies comparing different technologies and their learning outcomes. Some recent studies [4, 5, 33] measured learning in VR by using Bloom's taxonomy [8]. Interestingly, all these studies suggest that VR has potential to produce higher learning outcomes, such as applying, analyzing and evaluating. However, only the study by Parmar et al. [33] compared the difference between a VR-based learning environment and a desk-top-based learning environment. As a result, there is a need for more research on different learning technologies and their learning outcomes.

In order to fill this research gap, we adopt the design science research approach [34] to build and evaluate different design artifacts of various virtual learning environments. We compare three virtual learning environments (VR, 3D videos and 2D videos) as design artifacts in a controlled experiment. All the environments consist of the same contents and, after the experience, participants' learning is measured using the same assignments. The environments are designed to differ only on how the participant perceives them, which is measured with the affordances scale.

The results of this study provide insights on learning outcomes of various virtual learning environments. In addition, the results shed light on the differences of various technologies based on their perceived affordances. Thus, design principles [9, 18] for virtual learning environments are provided based on the results.

2. Literature: Learning in virtual environments

A virtual learning environment is a computer assisted learning environment including interactions with a computer or other similar device. The virtual learning environment can be seen as an entity comprising modern technology, web-based working and infinite information flow [24].

Most of the existing studies referring to the virtual learning environments deal with online or web-based learning environments such as Massive Open Online Courses (MOOCs), or 3D-learning environments consumed from the computer or mobile screens [19, 36]. Dalgarno and Lee [11] suggest that the virtual learning environments with 3D-objects and models enhance the spatial understanding, arousal, motivation, experiential and contextual learning. They also suggest that social learning as well as innovation and planning new ideas can be enabled by the virtual learning environments.

According to Wann and Mon-Williams [43] real-world environment can be expanded with 3D-learning environments and sensory effects including haptics, hearing, and visual effects. Consequently, this expands the interactions between the user and the learning environment in a way that is not possible in the real-world.

The immersive VR consumed with HMDs (later referred to as VR) as a virtual learning environment is an emerging technology where only few learning-focused studies exist. By the definition [48] VR is an artificial, computer-generated digital environment where the user connects and interact with. This environment may model some existing real-world or imaginary elements. In addition, the real-world physical boundaries, for example gravity, can be exceeded in the VR. The VR enables activities and interactions that are not necessarily available in the real-world or that are impossible to carry out or even dangerous in physical environments [41]. However, while the VR enables learning assignments and methods that cannot be carried out in the ordinary classrooms, it is not likely that it will substitute all the more conventional assignments and methods, such as classroom lectures and laboratory work [49].

The learning results in VR show that the technology is not improving the learning and efficiency, when the contents resemble the real-world [40]. In other words, there are no benefits from the VR if only the real-world elements are modelled, thus some elements that do not exist in the real-world are needed. However, complex systems and elements that are not easy or are even impossible to present with the traditional teaching tools and methods, work well for the VR. Such contents in VR can help students to concentrate [32]. Another study concerning the Augmented Reality (AR) learning environments showed that the AR improved learning results on the mathematical system in short-run, but in the long-run the effect was moderated [39]. The research results suggest that this may be due to the lower sensory effect provided by AR, while VR could hypothetically leave stronger engrams as it has more sensory effects.

The most obvious difference between the other virtual learning environments (e.g. online, web-based and MOOCs) and the VR learning environment is that VR is consumed with HMDs. This also enables a totally new interface for the user to interact with the 3D-models and the environment [20]. For example, as in online learning environments the user interacts with the content through the keyboard and mouse, in VR the user can actually grab the model and resize it by stretching and squeezing it and experience the object and the environment from different perspectives and contexts

[26]. These fundamentally different interfaces enabling different user interactions with the 3D-models and environments make the difference in the user-experience.

Several VR user-experience studies raise the immersion as a major research area [12, 13, 37]. The immersion refers to individual's feeling to empathize and emancipate in some environment [12]. Interactive digital media has been shown to create different levels of immersion. The immersion can improve the learning in several ways: learning from different perspectives, contextual learning, improved ability to apply learning into reality, improved understanding of complex issues [12]. In addition, it is suggested that multisensorial effects and interactions can contribute in creation of immersive experiences [12]. Thackray et al. [41] suggest that the immersion is a central and essential part of VR learning environments.

The existing Augmented Reality (AR) education research has discovered that the traditional teaching methods as such are not applicable and that AR technology can even have negative learning results [46]. These findings most likely apply to VR environments as well suggesting that completely new pedagogical approaches including objectives, contents, methods and assessments are required for VR learning environments [28].

2.1 Cognitive levels of learning

The Bloom's taxonomy [8] classifies the cognitive learning in six hierarchical levels. Later Krathwohl et al. [23] have revised this taxonomy to include remembering, understanding, applying, analyzing, evaluating, and creating. The Bloom's taxonomy is hierarchical as each level of the taxonomy relies on remembering and understanding which are the foundation for the higher levels of cognitive learning.

According to the theory of Krathwohl et al. [8], remembering is retrieving, recognizing, and recalling relevant knowledge from long-term memory. Understanding requires constructing meaning from oral, written, and graphic messages by interpreting, exemplifying, summarizing, inferring, comparing and explaining. Applying learning means carrying out or using a procedure for execution or implementation. In order to analyze one must be able to break elements into constituent parts and determine how the parts relate to each other or to larger entity or purpose. Analyzing also requires ability to differentiate, organize and attribute subjects. Evaluation means ability to make judgments based on criteria and standards through checking and critiquing. In the highest level of the taxonomy, creating requires ability to put elements together to form coherent and functional entities. Furthermore, at this level, one must be able to generate, plan and produce new patterns and structures, but also to recognize the occurring changes. The traditional methods of teaching and training are mostly focused on the lower levels of Bloom's taxonomy, but VR has the potential to impact higher levels of Bloom's taxonomy (applying, analyzing and evaluating) [33] as training in VR involves also the practical level.

In addition, most of the existing learning studies regarding VR environments have concentrated on the lower levels of Bloom's taxonomy (remembering and understanding) ([14, 38]) while applying and further higher levels have not been so much under consideration [33]. In this study, we tested the remembering, understanding and applying -levels, which are described later in the method -chapter.

3. Research framework and questions

In order to explain the differences in various learning environments, we adopt the learning environment affordances into the research framework. The term affordance has emerged in the late 1970's in the field of perceptual psychology ([16, 17]). According to Gibson [17], affordances are relationships between reality and a user - a relationship exists naturally, and it is not necessarily visible, known or desired. Norman [30], divides the affordances to real and perceived affordances. The perceived affordances are visible and recognizable features and qualities for the users. User finds these perceived affordances meaningful and useful with a known outcome. The real affordances, on the other hand, are all the possibilities that the system can potentially deliver. It is the designer's task to choose and contemplate which of the real affordances should be brought visible for the user i.e. turn to be perceived affordances [30].

Since the introduction of the concept of affordances, the design science literature has adopted the terminology introduced originally by Norman [30]. The term is also often used in the design of pedagogics and virtual learning environments where both teachers and students can evaluate the affordances and these observations can be used to develop the system [44]. Bailenson et al. [1] suggested several unique affordances for the virtual learning environments. In virtual learning environments the following things are possible, for example: user can be an embodied teacher or learner, co-learners can exist in the virtual learning environments, enhanced and complex visualizations can be done, recordings or synthesis modelling previous behaviors can be conducted, contextual presence can be accomplished through immersion, dangerous or expensive lessons can be simulated and teachers and students are able to alter their online representations and contexts. Bailenson et al. [1] findings show that especially the affordances related to the sociability, social interactions and social cues are crucial for learning.

Another article by Dede [12] concluded in a review that immersion in a virtual learning environment can enhance education in at least three ways: by enabling multiple perspectives, situated learning, and transfer from classroom to real-world settings. The study also noted that even lesser degrees of immersion can still provide situated learning experience.

Ke et al. [21] considered three affordances of the virtual learning environments. First affordance is the virtual agents and avatars that act in a way that is personalized and impossible to run in the real-world. Second affordance relates to the imagination, customization and infinitive solutions provided by the virtual learning environments. These properties enable creation of several various learning scenarios. In the third affordance they mention the sensory effects strengthening the learning experience. According to their results all these three affordances affected teachers sense of presence in the virtual classroom and also their virtual teaching performance.

In their review on previous literature, Dalgarno and Lee [11] recognize five affordances for the virtual learning environments. These affordances include "the facilitation of tasks that lead to enhanced spatial knowledge representation, greater opportunities for experiential learning, increased motivation/engagement, improved contextualization of learning and richer/more effective collaborative learning as compared to tasks made possible by 2D alternatives".

As these literature examples show there is plenty of research introducing various virtual learning environment affordances, however, there still seems to be a lack of research using affordances as powerful design tools for virtual learning environments. More specifically, while we know many virtual learning environment affordances, we do not exactly know how these affordances vary between different technologies as there are no explicit experiments showing this. This could also offer some first-hand information whether the affordances could be used to explain the different learning outcomes with different technologies. By understanding the differences in various learning environment affordances, one could also make better arguments when choosing one technology over another or when trying to find technologies that complete each other for a learning environment. In this regard, it is also necessary to know the learning capabilities with different technologies. Having these issues as our motivation for the study, we draw our research questions:

Research question 1: Does the different technology (VR, 3D, 2D) result in different perceived affordances i.e. can the affordances -theory be applied in building and explaining different learning environments?

Research question 2: What is the effect of the technology (VR, 3D, 2D) on different learning outcomes (understanding, remembering and ability to apply)?

In our study, we take three different virtual learning environments VR, 3D and 2D -videos as according to the previous literature these environments potentially provide different levels of affordances [1, 12, 21]. In the experiment, for each technology we measure the perceived affordances and the learning outcomes in terms of understanding, remembering, and ability to apply.

4. Data and Methods

Our study adopts the design science research methodology [3]. The research questions introduced above specify the research problem and objectives for the research. We built three different design artifacts representing three different virtual learning environments (VR, 3D and 2D).

The VR learning environment was built with the Mrs. Tudio do-it-yourself platform developed on the Unreal Engine game engine (Mixed Reality Hub, University of Helsinki). The Mrs. Tudio allows any teacher and student to create and edit their own VR content. In our case, one craft teacher made the virtual environment and recording with no previous experience on such work. With the help of a research assistant such an environment and recording were made in couple of hours. The environment consisted of eight vertical strings (left screenshot in Figure 1). Using these strings and a drawing tool, a teacher made a recording in VR which could be replayed and showed as an avatar in VR. The VR learning environment was presented with the HTC Vive HMD allowing free moving and therefore changing the viewpoint for the research subjects. The 3D -video virtual learning environment presented the same recording made in the VR, but it was consumed from a laptop screen. The user was not able to change the viewpoint as it was played as a normal video. The 2D -video was otherwise identical to the 3D -video, but the objects in the environment were 2D. The 2D –video can be considered to be closest to conventional video recordings made in classrooms without any available 3D –objects (right screenshot in Figure 1). However, in this experiment all the recordings were made in VR to minimize any uncontrolled differences. In all recordings the same topics were introduced with the same voice and

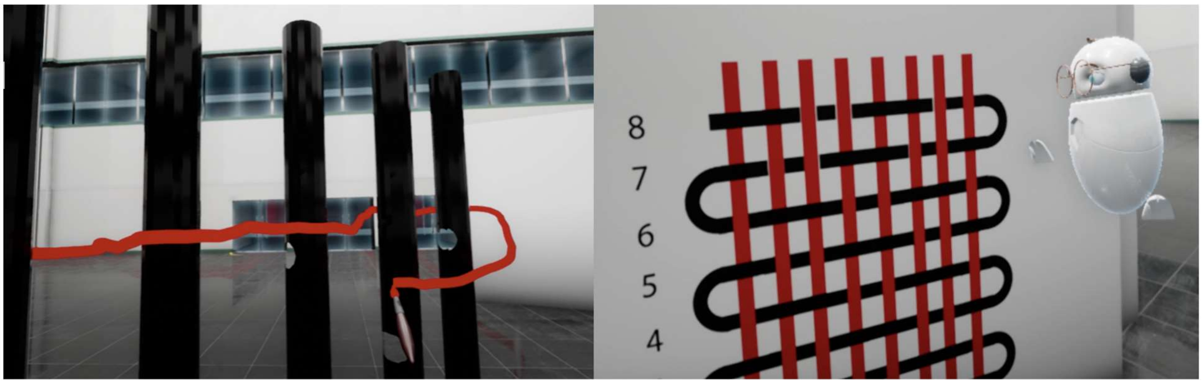

Figure 1. Screenshots from 3D (left) and 2D -videos (right). The VR recording was exactly the same as the 3D video but consumed with the HMD and so allowing free moving and therefore changing the viewpoint.

with same avatar figure. The research subjects were advised to follow the respective recording without any options to pause, rewind or ask additional questions.

All three design artifacts were demonstrated in a controlled 1x3 between-subjects experiment. In a VR lab located in a metropolitan city center, altogether 97 people participated in the experiment individually. The main idea of a between-subjects experiment is to randomly assign research subjects to the different treatment groups and compare the outcomes between the groups [25, 42].

In terms of evaluation, the learning outcomes were measured including different levels of learning: understanding, remembering and ability to apply [12] which were also the learning objectives for the experiment exercise to learn the structure of twill weave. The understanding was measured with a textile recognition assignment: there were five different textiles out of which one was correct. This was tested with pre- and post-tests to control that people were not familiar with the subject beforehand, as we wanted to test learning in the experiment. Only one participant was removed from the data analysis due to being already familiar with the subject. In this regard, the research context was found to be very suitable as it provided a straightforward 3D assignment from many existing topics on the curriculum of handicrafts, but with a little previous knowledge among the general population. In order to test the ability to apply, a drawing assignment was carried out. In this assignment, there were eight vertical strings on a paper. The task for each participant was to draw the horizontal strings in the same way that it was taught by the avatar in VR / 3D / 2D. The same drawing assignment was repeated after two weeks to test the remembering. Altogether 32 participants participated in this assignment. The data was analyzed using cross-tabulations with counts and percentages where we tested technologies (VR, 3D and 2D) and learning outcomes (understanding, remembering and ability to apply) by using the Pearson Chi-Square test with a significance level of 0.05 [21]. We also used all the background variables (gender, age, occupation and use of VR devices before) as layer variables in order to measure the interaction effects of these background variables and the technologies on the learning outcomes.

In addition to the learning outcomes, we evaluated also the perceived affordances for each design artifact, which were measured using a 7-point Likert-type scale (1=strongly disagree; 7=strongly agree). The scale development is exploratory in nature and the chosen items are based on a literature review introduced in the theory framework –chapter i.e. identified affordances for virtual learning environments [1, 11, 12, 21]. For the measured items we calculated means and standard deviations. In addition, we used the non-parametric analysis of variance (Kruskal-Wallis) with a significance level of 0.05 [21] to test whether there are significant differences in the perceived affordances as a result of the experienced technology.

The last activity in the design science research methodology [34] is communicating the results. Considering the limitations of our study (raised in the conclusion –chapter), we propose design principles for the VR learning environments. Unlike a design theory, the design principles are only explicit extractions on the way towards more developed knowledge base and design theory [18]. In addition, Chaturvedi et al. [9] notes that any proposed design principles may vary due to considered dimensions, design models, goals, involved designers, developers and platforms.

5. Results

Altogether 97 people participated in the experiment, while 96 were included in the analysis. Out of the total 28 (30%) were assigned to the VR, 34 (35%) to 3D and 34 (35%) to 2D experiment. The background variables included gender, age, occupation and the use of VR devices before. Out of the all participants, 37% were males and 63% females. Less than 3% were under the age of 18, while the age group of 19-24 years was the majority (42%), followed by the age group of 25-34 (41%), while 13% were 35 years or older. Out of the total, 43% had previous experience with some VR devices. In terms of occupation, 72% were students, while 28% were others with 21% employed, 2% unemployed and 5% something else.

Following the framework, we tested learning outcomes on remembering, understanding and applying with different technologies. The results showed no statistical significance between the technologies when measuring the learning results of understanding and remembering. Table 1 shows the cross-tabulation results for the learning results "ability to apply" and different technologies. The results show the highest rate of correct answers in VR. However, the Pearson Chi-Square test showed no statistical significance when comparing all the technologies, while the pairwise comparisons showed a significant difference between the VR and 2D (p= 0.044) learning results. These findings suggest that while there are no significant differences between the VR and 3D as learning technologies, VR outperforms compared to 2D.

Table 1. The cross-tabulation results for the learning results "ability to apply" and different technologies.

	Correct	FALSE	Total
VR^*	21 (75%)	7 (25%)	28
2D*	17 (50%)	17 (50%)	34
3D^	23 (68%)	11 (32%)	34

^Pearson Chi-Square 4.526 (p=0.104)
*Pearson Chi-Square 4.045 (p=0.044)

In terms of the perceived affordances, Table 2 shows the means and standard deviations for each technology as well as for the whole sample. In addition, the Kruskall-Wallis test results and significances are reported. According to these results, the perceived affordance items 6, 7, 10, 11, 13, 14, 15, 18 and 20 were significantly different between the VR, 3D and 2D technologies with the highest means for the VR. These items (named customized learning, challenging learning environments, multi-sensory effects, immersion, interactivity, 3D-dimensionality, engagement as well as motivation towards the content and technology) differentiate VR from other technologies and as a result they are the proposed design principles for the VR learning environments. The implications of these results are discussed in the next chapter.

6. Discussion

In this study, we assessed three different virtual learning environments (VR, 3D and 2D -videos) and measured the perceived affordances as well as the learning outcomes in terms of understanding, remembering and ability to apply. The motivation was to find out whether the affordances can be used in building and explaining different learning environments. In addition, we were interested to learn what kind of learning these different technologies enable and how these technologies should be used in building learning environments.

Our proposed design principles for the Virtual Reality learning environments are twofold. First, considering the Bloom's taxonomy our results suggest that the VR has its advances on the apply -level or higher. This finding is very much in line with the study by Parmar et al. [33]. While they were comparing teaching contents between HMD and desktop-screen, our study added to this comparison also 3D and 2D videos. These results suggest that in designing virtual learning environments, choosing the technology must be aligned with the learning objectives. Choosing and aligning teaching objectives, contents, methods and assessments is part of the constructive alignment framework in teaching [6], however, there is a lack of literature considering the alignment and technologies (e.g. [2]) and this is certainly a research field requiring further attention. Moreover, as the Bloom's higher levels have generally been found to be more difficult to teach and evaluate compared to the lower levels, they have not been implemented as extensively in most curriculums [3]. Our results suggest in line with the previous research that VR can easily provide new teaching methods also on higher levels of learning [14, 38]. In addition, our results comparing the affordances of different technologies (VR, 3D, 2D) suggest several other design principles e.g. customized learning, challenging learning environments, multi-sensory effects, immersion, interactivity, 3D-dimensionality, engagement as well as motivation towards the content and technology. These principles were significant explaining the differences of VR compared to the other two technologies (3D and 2D).

Table 2. Means, standard deviations and analysis of variance (Kruskall-Wallis) -test results.

	VR		3D		2D		Total		Kruskall-Wallis
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Sig.
1. I think this application makes it possible to visualize the learning content (fabric texture).	6.21	0.82	6.09	0.93	5.97	0.97	6.08	0.91	0.63
2. This application makes it possible to visualize complex systems (e.g. fabric texture).	6.17	0.89	6.00	0.89	6.06	1.13	6.07	0.97	0.58
3. I think this application makes it possible to visualize abstract phenomena.	5.76	1.02	5.32	1.22	5.38	1.26	5.47	1.18	0.38
4. I think this application makes it possible to visualize microscopic things.	5.69	1.51	5.76	1.10	5.88	1.32	5.78	1.30	0.73
5. I think this application makes it possible to duplicate different learning tasks.	5.86	1.16	5.41	0.99	5.82	1.11	5.69	1.09	0.10
6. I think this application makes it possible to modify different learning tasks.	6.07	0.88	5.38	0.89	5.97	0.94	5.79	0.95	0.01*
7. With this application you can make learning tasks which are e.g. expensive, dangerous or impractical to implement in traditional classroom.	6.31	1.00	5.91	0.79	6.21	1.15	6.13	1.00	0.03*
8. I think that I can apply knowledge acquired from the application into practice.	5.32	1.54	5.15	1.52	5.24	1.63	5.23	1.55	0.88
9. Application made collaborative learning possible.	3.93	1.62	3.68	1.68	4.18	1.82	3.93	1.71	0.59
10. I experience this application as multisensory.	5.97	1.02	4.29	1.64	4.74	1.44	4.95	1.56	0.00*
11. I got immersed to the application.	5.83	1.31	4.18	1.53	3.76	1.50	4.53	1.68	0.00*
12. I felt indisposition and dizziness in the application.	1.62	1.21	1.50	1.02	1.41	0.86	1.51	1.02	0.68
13. I felt that I was interacting with the teacher in the application.	4.03	1.82	3.00	1.94	2.24	1.44	3.04	1.87	0.00*
14. Application helps me to visualize in 3D.	6.14	0.95	5.65	0.98	4.79	1.47	5.49	1.28	0.00*
15. I felt that I was interacting with the 3D model in the application.	5.41	1.84	4.56	1.46	3.85	1.78	4.57	1.79	0.00*
16. This application helped me to visualize the texture of the fabric.	6.03	0.87	6.06	1.13	5.97	1.00	6.02	1.00	0.80
17. Learning content (fabric texture) was easy to study with the application.	6.07	0.92	5.65	1.52	5.29	1.53	5.65	1.39	0.12
18. This application grew my engagement and motivation towards the learning content (fabric texture).	5.24	1.41	4.24	1.46	3.82	1.60	4.39	1.59	0.00*
19. This application rose my interest to study the topic (fabric texture) more deeply.	4.14	1.83	3.88	1.49	3.47	1.86	3.81	1.73	0.34
20. I think learning with this application were more motivating than in a real classroom.	5.66	1.45	4.35	1.79	3.94	1.77	4.60	1.82	0.00*

*Statistically significant result with the significance level of 0.05.

The previous research has found that the VR is capable of providing multi-sensorial effects and interactions [43] that can contribute to individual experiences and immersion [12]. Our results show support for those findings. In addition, our results suggest that through these features, the VR can support the customized learning which has been found to have many positive effects in terms of learning performance [29]. In terms of understanding 3D-dimensionality, VR can provide an advantage over the other technologies and according to Zhang [47] it provides an intuitive experience with low learning requirements. Body movements such as head rotation that represent interactivity, also promote feeling of presence [35]. These kinds of intuitive interactions are proposed to create flow [10]. Our results support those findings. For the design, however, choosing the right 3D models is also a strict cost-benefit issues as the 3D modelling is very time- and money consuming. Several studies suggest that the chosen 3D models should be unique and not accessible in the real world [41, 43] where also our results are confirmatory. In addition, while there are many available ways of reducing the costs of 3D modelling, e.g. 3D asset libraries and do-it-yourself engines, research focused on learning with these platforms and methods is completely absent. We suggest that combining these aforementioned platforms and methods with the state-of-art teaching methods e.g. research- and phenomenon-based learning can be a new and interesting research avenue to introduce and develop these concepts in the design of virtual learning environments.

The virtual learning environments have been found to be motivating in general [11,31]. Our results suggest that the VR learning environments can show higher motivation compared to the two other technology environments (3D and 2D). While there is a possibility that the technology used can also alone improve the motivation, our results showed that VR both increased the engagement towards the subject as well as it was also found to be more motivating learning environment and technology. The design implication for the virtual learning environments is to consider these individual motivation and engagement paths perhaps with the help of providing multi-sensorial effects and interactions and by doing so customizing the learning experience. Furthermore, this raises a question, whether the more customized learning experience with multi-sensorial effects and interactions can also build the motivation and engagement especially towards the content.

7. Conclusion

As a conclusion, we found using the affordance framework very useful in evaluating the different properties of technologies. The use of such a framework is thus suggested for the researchers and designers when validating and justifying the use of some technologies in the virtual learning system designs. While the framework items developed in this study where based on the literature review on affordances in the field of virtual learning environments, our suggestion is that the same approach could be used to several other fields where the technology affordances are commonly researched, such as in sales research. In this regard, we feel that the approach of using the affordances in this study introduced a concrete and applicable tool that could be further applied and studied in the design science research.

What it comes to the limitation of this study, we considered only few learning outcomes named remembering, understanding and ability to apply. As defined by Krathwohl et al. [23], there are also several other cognitive levels of learning that should be considered by the future research. In addition, we cannot be sure that we actually tested the different levels of the taxonomy, while there can also be some overlapping elements [50]. This is also something to be considered when planning the tasks and evaluations for the learning environments. Furthermore, with our data we could not indicate that the proposed VR design principles would have any significance in terms of improving the VR environments' learning outcomes or if they change over time (e.g. with more familiarity with the system use). Moreover, we cannot say that the chosen affordance items for the scale are exhaustive. Therefore, further exploring and experimenting these proposed design principles and learning outcomes is a suggestion for the future research.

As many previous studies have found that the VR is to some extent immature technology as a learning technology, our results suggest that for the specific learning objectives it can be a powerful tool. In order to make VR environments more effective for learning, one has to design learning tasks so that they can take full advantage of the technology.

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